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DEVELOPMENT OF A WATER-MIST BASED VENTURI SYSTEM FOR DUST CONTROL FROM MAINGATE CHOCKS AND BSL

Ting Ren¹, Graeme Cooper² and Srinivasa Yarlagadda³

ABSTRACT: Advances in modern longwall (LW) technology have resulted in high production faces with more powerful chocks and shearers that can advance at faster rates. As longwall chocks (supports) advance, crushed roof coal and/or rock can fall from the top of the chock canopy into the face ventilation airflow. Dust survey showed that chock movement is a significant source of dust exposure for shearer operators, accounting for about 47% of total LW face dust make during the cutting cycle. 3D CFD models have been developed to understand the behaviour of longwall dust particles from various sources including maingate (MG) chocks and stage loader/crusher. Modelling results demonstrated that much of the respirable dust particles generated from MG chock movements and the beam stage loader (BSL) will disperse onto the longwall face ventilation, contributing significantly to dust exposure levels. Dust control systems using ultra fine water-mist technology have demonstrated promising results in encapsulating respirable dust particles. A prototype water-mist based venturi system has been developed to firstly produce ultra-fine water droplets (5-15 μm) for suppressing the respirable dust particles from the MG chocks/BSL; and secondly induce a water-mist airflow with sufficient momentum to divert dust clouds off the walkway area along the face. The new system will be trialled on MG chocks in medium to high seam longwalls on which dust contamination appears to be more problematic.

INTRODUCTION

Respirable dust particles have long been known to be a serious health hazard to workers in coal mining. Prolonged exposure to excessive levels of airborne respirable coal dust can lead to coal workers' pneumoconiosis (CWP), progressive massive fibrosis (PMF), and chronic obstructive pulmonary disease (COPD). These diseases are irreversible and can be debilitating, progressive, and potentially fatal in their most extreme cases.

Dust particles can be generated from several sources on the longwall, primarily including shear cutting, chock movements, stage loader/crusher and intake contaminations. A recent dust survey by Gillies Wu Mining Technology using real-time Personal Dust Monitoring (PDM) units showed that the advancement of MG chocks leads to significant dust falling into the face airstream, accounting for about 47% of total LW face dust make at the Shearer operator position during the cutting cycle (Gillies and Wu, 2008); The survey also indicated that if the BSL scrubber is not working optimally, the bulk of the dust particles will escape over the BSL and end up on the face increasing the overall dust levels.

Effective dust control is important for the occupational health and safety of production crews and eventually production outputs. A variety of water spray dust control systems have been trialled, and some have been applied in the field with mixed results (Goodman, 2000; Pollock and Organiscak, 2007). Dust control systems based on water mist technologies have also been tested and more recently trialled in underground coal mines Australia and overseas with promising results. Dust suppression systems using water mist technology have recently been tested at conveyor transfer points and demonstrated promising results. Water droplets from the water mist system are of a comparable size (1-10 μm) to respirable dust, and thus can be used more effectively to knock-down dust particles before they become airborne.

ACARP is supporting a project to develop and test a new type of venturi system based on ultra-fine water mist technology to reduce respirable dust contamination on medium and thick seam longwall faces, particularly those dust particles from the advancement of MG chocks and the intake ventilation passing the BSL. This new venturi system will be developed as a stand-alone unit that can be easily attached to the chock canopy with minimum interaction with other longwall equipment. This paper reports the development of this new dust control system.

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DUST FROM LONGWALL MG CHOCKS - BASELINE DUST SURVEY

Gillies and Wu (2007; 2008) conducted extensive real-time respirable dust monitoring and baseline surveys on Australian longwalls. The results from a LW face baseline survey located in the Bowen Basin, Queensland, are shown in Figure 1. Two real-time PDM were placed at separate locations (#134 shadowing the MG shearer operator and #139 at the MG Chock 8 position) on the face to measure the dust exposure. During the cutting sequence from MG to TG, 1-5 MG Chocks were advanced immediately after the shearer passed. This action leads to much dust falling from the advancing chocks; dust levels registered by both PDM units were increased significantly, accounting for about 47.8% of total longwall dust make at the Shearer MG operator's position during the cutting cycle, as indicated in Figure 1. This measurement was in agreement with another longwall dust survey conducted by Gillies and Wu (2007). Similar observations have also been reported at other mines in Australia.

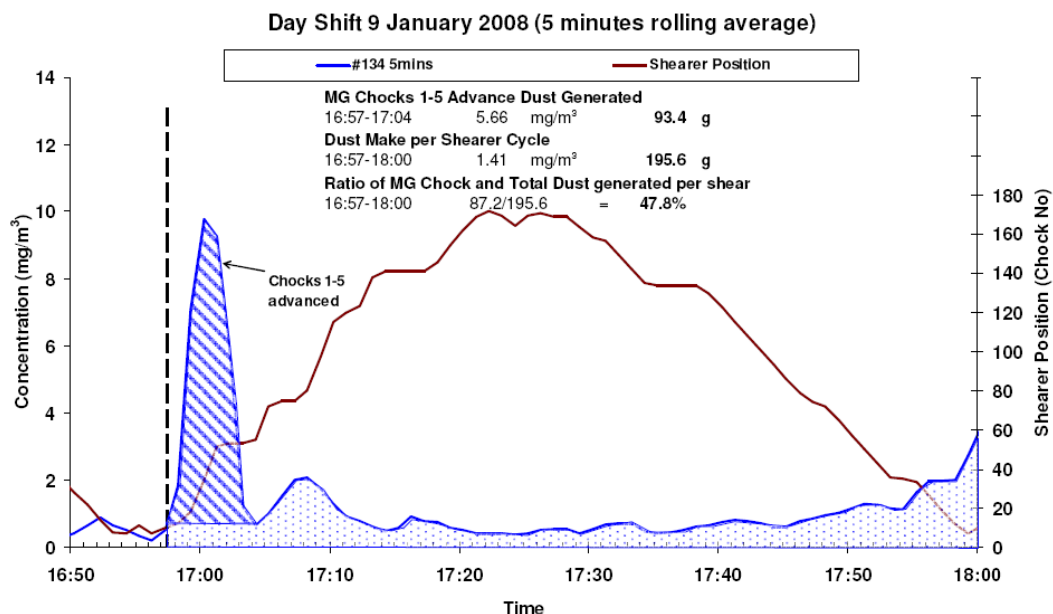


Figure 1 - Dust survey on a longwall showing MG Chocks (1-5) advance dust versus total longwall dust make at Shearer MG and TG Operator positions (Gillies and Wu, 2008)

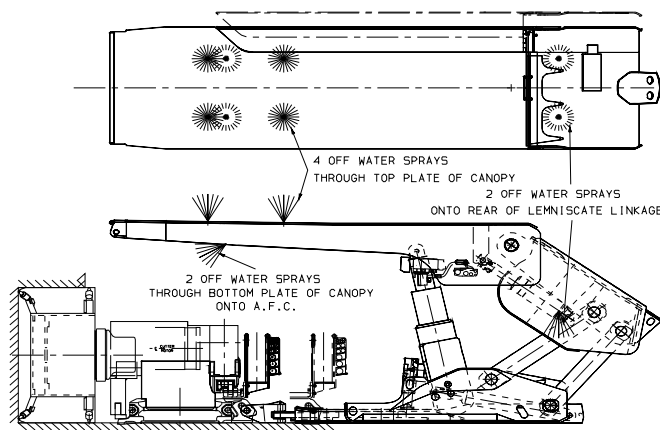
The dust baseline survey results demonstrated the importance of reducing respirable dust generated from the advancement of MG chocks thereby significantly mitigating total dust make to the longwall face. Dust monitoring also showed that the BSL can be another major dust contributor, even for longwalls equipped with a BSL dust scrubber. Dust surveys indicated that the scrubber can cleanse only a portion of the air travelling to the face, allowing much of the dust particles to escape over the BSL and to end up on the longwall face, increasing the threshold dust levels in the ventilation air.

DUST CONTROL FROM CHOCK MOVEMENT

Longwall supports are typically advanced within two or three shields of the trailing shearer drum. As longwall chocks (supports) are lowered and advanced, crushed roof coal and/or rock falls from the top of the chock canopy directly into the face ventilation airflow. Most of this dust becomes airborne, and quickly disperses into the walkway. As a result, chock movement can be a significant source of dust exposure for shearer operators when supports are advanced behind the shearer during MG to TG cuts. To control dust from chock movement, a number of methods have been developed (Colinet, *et al.*, 2010). Two such systems are:

- **Canopy-mounted spray systems** - A canopy spray system that activates water sprays into the roof material on top of the supports for a short period of time before and during chock movement to wet the material on top of the canopy to lower dust levels during shield advance, as shown in Figure 2.a. Experience in the US and Australia has shown that this type of system is hard to maintain and is not effective in distributing moisture to the material above the canopy.

- **Shield sprays under the canopy** - These sprays were automatically activated by the position of the shearer to create a moving water curtain in an attempt to contain the dust cloud near the headgate and tailgate drum areas, as shown in Figure 2.b. Proper on/off sequencing of these sprays is critical to supplement the directional spray system. These sprays need to be properly aligned toward the face to enhance the envelope of clean air created by the shearer's directional spray system.



(a) Spray system over canopy



(b) Spray system under canopy

Figure 2 - Water sprays located above and on the underside of the canopy (Colinet, *et al.*, 2010)

DUST CONTROL USING WATER MIST

Historically water sprinklers/hoses have been used for dust control on longwalls to suppress the dust particles before they become airborne (Goodman, 2000; Colinet, *et al.*, 2010). The fundamental principles for dust suppression is to allow the water drops to collide with dust particles in the air, forming heavy agglomerates of dust and water, resulting in a "settling out" of the airborne dust. However, conventional hydraulic water sprays are not effective on respirable dust. With typical diameters of 200-600 μm sprays, the droplets are much larger than the dust particles they are attempting to suppress. Water drops that are too large will not collide with the finest, most hazardous dust particles smaller than 10 μm . Airborne water droplets and dust particle attraction is most likely to occur when the droplets and dust particles are of similar size.

As shown in Figure 3, consider a water droplet is about to impact on a dust particle, or aerodynamically equivalent, a dust particle about to impact on a water droplet, if the droplet diameter is much greater than the dust particle, the dust particle would simply follow the airstream lines around the droplet, and little or no contact would occur; whilst if the water droplet is of a similar size to that of the dust particle, contact would occur as the dust particle tries to follow the streamlines. Thus the probability of impact can be increased by

- Increasing the number of smaller sized spray droplets per unit volume of water utilised;
- Optimising the energy transfer of spray droplets with the dust-laden air.

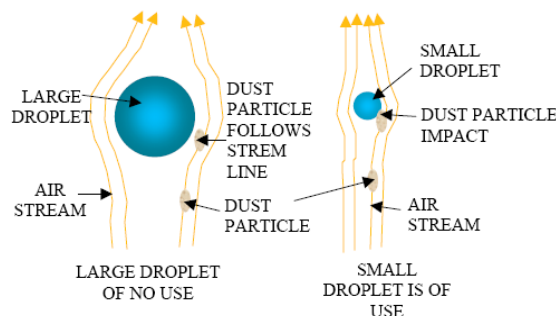


Figure 3 - Water spray and mist technology for dust control (Joshi, 2009)

Dust suppression systems using ultra fine water mist technology have recently been tested in underground coal mines and demonstrated promising results. In Australia, a simple dust suppression system using ultrasonic atomisers has been installed at the MG transfer point at Broadmeadow and excellent dust control result has been observed (Burgess, 2009). Also at Broadmeadow, a simple water mist system is being tested for dust suppression from longwall chocks and promising results demonstrated. Similar initiatives are being considered in other Australian coal mines. In South Africa, a fogger system using water mist technology has been investigated at Thandeka and Twistdraai as water curtains on the intake airway and transfer points (Schoor, 2010). Field results proved that the system was highly effective by reducing dust concentrations by 96% during the test periods. Also in South Africa, an air mover system known as Terrajet® has been under development by Terramin and trialled in the field with promising results (Schoor, 2010).

It was therefore proposed to develop a water mist based venturi system that could be attached to the canopy of MG chocks to suppress respirable dust particles from chock movements and intake air streams passing the BSL, whilst also acting like a directional spray system to enhance the diversion of dust clouds away from the walkway areas along the longwall.

CFD MODELLING OF DUST DISPERSION FROM MG CHOCKS AND BSL

CFD models

The behaviour of respirable dust on a longwall face is a complex process because of the nature of longwall operations. The generation, dispersion and transport of airborne dust are mainly governed by the spatial velocity and the movement pattern of the ventilation air. To understand the dust behaviour and thereafter assist in the design and evaluation the effectiveness of dust control techniques, ACARP has been supporting research projects based upon CFD modelling to improve the understanding of dust flow patterns around the longwall shearer, and the study of a range of dust control options/concepts for reducing operators dust exposure levels (Ren and Balusu, 2010). In this study, three dimensional CFD models were built to represent longwall faces in medium and thick seams. These models consist of a section of the full scale coal face and the maingate, and embody the major longwall components such as chocks, shearer, spill plate, BSL/crusher and conveyor. In addition, an array of water mist injection points were incorporated into the model along the chocks and around the AFC-BSL transfer point where the venturi units are likely to be installed based upon field observations. Figure 4 shows the layout of the longwall CFD model.

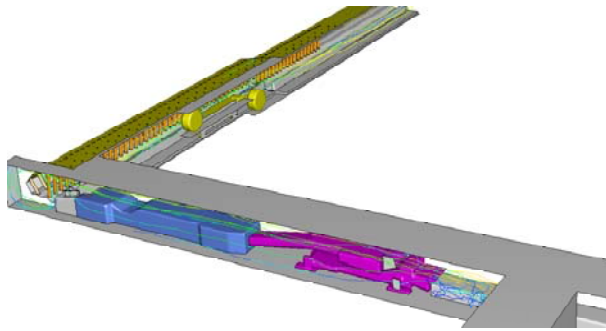
Base model simulations were carried out with a variety of intake airflow rates, ranging from 50 m³/s to 100 m³/s without the intervention of any dust controls. The base-case CFD models were calibrated and validated against field airflow velocity data obtained from field ventilation data and used for further parametric studies of the water mist venturi systems.

Dust flow modelling

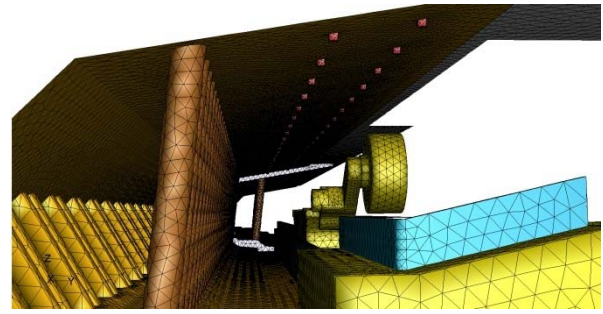
A major challenge in this study is the modelling of respirable dust particle dispersion in the turbulent flows on the longwall face. Longwall airflow is highly turbulent due to the large quantify of air supply and the existence and movement of mining equipment, and such turbulent flows will impact on the dispersion of respirable dust particles along the face. For this study, the standard $k - \epsilon$ Model was chosen to model the turbulent airflow in the longwall face. In addition, the uncoupled approach was adopted to model the dust particle dispersion patterns, in which all the dust particles were treated as 'respirable' and as such the discrete phase (respirable dust particles) will not impact the continuous phase flow (airflow) pattern. Essentially, all the simulations were carried out as a single phase steady-state model.

Base-model simulations were conducted to investigate the behaviour of respirable dust dispersion from various sources on the longwall. In these simulations, a group of dust particles were 'released' as coal-hv (material) with particle sizes between 1~10 µm. It was assumed the particle size distribution from these releasing points follows the Rosin-rammler distribution function. The dispersion of particles due to turbulence in the continuous phase flow phase (air) was tracked using the stochastic tracking model, which includes the effect of instantaneous turbulent velocity fluctuations on the particle trajectories through the use of stochastic methods. Figure 5 shows the tracking of dust particles released from outbye (belt road), AFC-BSL transfer point, and MG chocks. CFD modelling results show that much of the respirable dust particles generated from chock movements near the MG and the BSL will end up on the

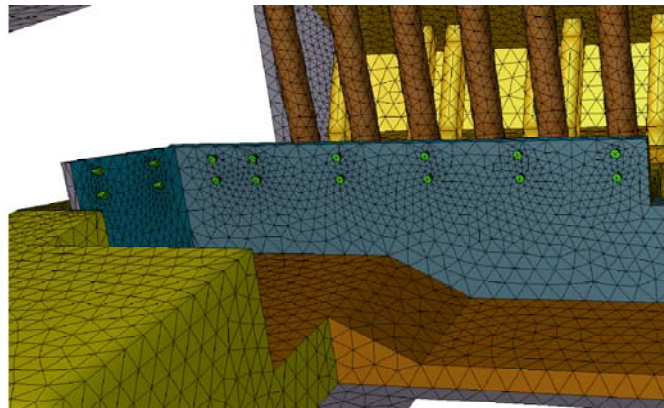
longwall following the ventilation, contributing significantly to dust exposure on longwalls, if not controlled by effective dust mitigation methods.



(a) Geometry of the longwall CFD model

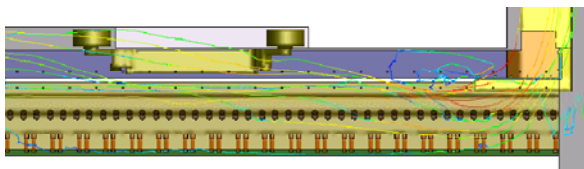


(b) Computational grid of the longwall CFD model with 'venturi units' on longwall chocks

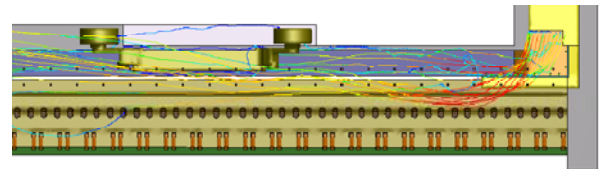


(c) Computational grid of the longwall CFD model with 'venturi units' around AFC-BSC transfer point

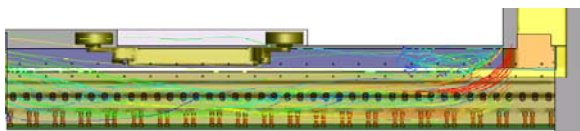
Figure 4 - Layout of the longwall CFD model for dust modelling



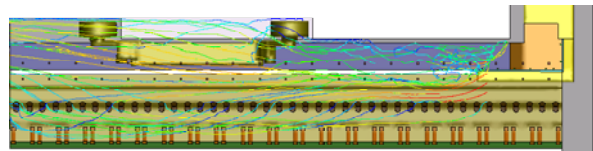
(a) Dust particles from outbye (Belt road)



(b) Dust particles from AFC-BSC transfer point



(c) Dust particles from MG chocks 1-2



(d) Dust particles from MG chocks 4-5

Figure 5 - CFD modelling showing dust dispersion from belt road, BSL and MG chocks

Operational experiences have demonstrated that it is unlikely to achieve total dust capture for any longwall dust control systems due to the large cross sectional area and very high airflow on the face. Therefore, the water mist based venturi system, in addition to capturing a proportion of the dust particles, must be positioned to divert dust particles away from operators' walkway area.

Modelling of water mist venturi

To optimise the position of the water mist venturi units on the MG chocks, the base CFD models were used to conduct parametric studies on a number of combinations of venturi positions along the MG chocks (1-6) and on the AFC/BSL plate, including:

1. With venturi attached the chock canopy

- Venturi at canopy level – towards the coal face;
- Venturi at canopy level but tilted along the face (10~45°);
- Venturi tilted down and along the face.

2. With venturi stationed on the AFC/BSL plate

- Venturi spray towards the coal face;
- Venturi spray with angles along the face.

In all cases, the water mist injection was modelled as 'air spray' as much of the spray would be of compressed air with a small portion of fogged water droplets. This also avoids the complexity of modelling multiphase flow which would require much computing power and time. Figure 6 shows the impact of venturi units oriented at different locations on the diversion of dust particles from both MG chocks and the AFC-BSL transfer point. Modelling results show that a more effective control of dust particles from MG chocks and BSL can be achieved by:

- Slightly tilting the venturi units towards the floor and the coal face with optimum angles between 15-20° down and 45° along the face;
- Installing two venturi units on each chock;
- Installing two venturi units on the AFC/BSL plate;
- Installing a batch of venturi units in the first 6 MG chocks to achieve the overall dust flow streamlining effect.

Results from the CFD modelling will be used to assist field trials of the newly developed water mist based venturi systems as described below.

PROTOTYPE WATER MIST VENTURI UNITS

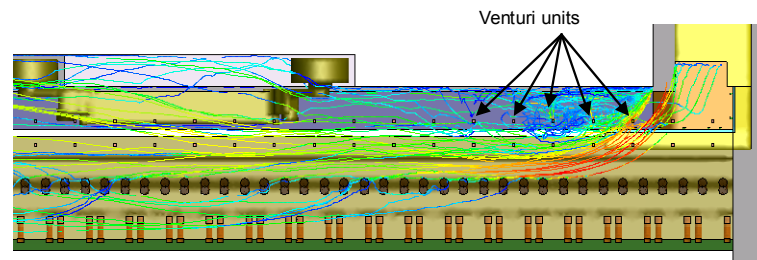
Using the latest development of ultrasonic nozzle technology, a new prototype of water mist venturi system has been developed to perform the following two functions:

- To produce uniformly-distributed ultra-fine water droplets (5 - 15 μm) for encapsulating and trapping a high proportion of the respirable dust particles from the MG chocks/BSL before they become airborne and reach the walkway area;
- To induce a controlled volume of water-mist airflow with sufficient momentum for diverting and suppressing respirable dust clouds from MG chocks/BSL off the walkway area along the face.

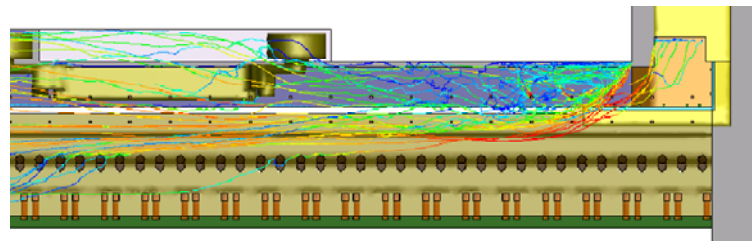
To achieve the above design requirements, extensive laboratory tests were carried out with different venturi chamber diameters (42 ~ 70 mm), different venturi lengths, methods for mounting the ultrasonic nozzles, as well as air pressures (ranging from 8 - 2 bar) and water pressure (ranging from 6 - 1 bar). The ultrasonic nozzle holder assembly with different nozzles was used to test the best combination and various distances between the nozzle and the venturi to optimise the water mist production and air induction effect. Tests results indicate that the 70 mm (diameter) x 143 mm (length) venturi is capable of producing an optimum spray coverage and spray distance of approximately 10-12 m. Figure 7 shows the various parts of the venturi unit and laboratory testing process.

This new venturi system essentially consists of a water mist generating chamber incorporating mounting holes via which water and compressed air can be introduced to the ultrasonic atomisers that produce very fine droplets. Water is ejected through a number of orifices into the nozzle air outlet channel, where the high velocity air stream produces a first liquid breakup through shear action. The air stream, carrying

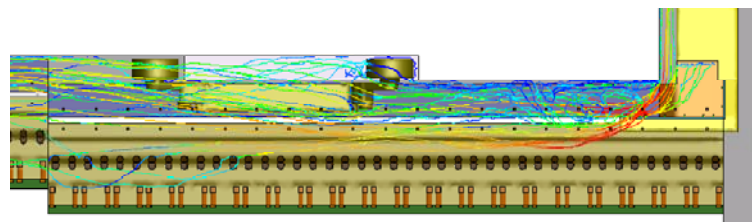
the droplets, collides with a resonator placed in front of the nozzle outlet channel that generates a field of high frequency sound waves. Water delivered to the resonator is shattered into fine droplets which are then carried downstream by air by-passing the resonator.



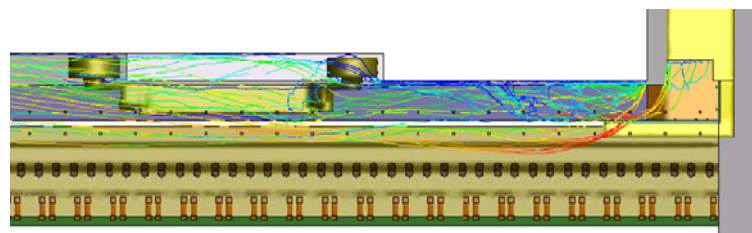
(a) Venturi at level but tilted at 20° along the face



(b) Venturi at level but tilted at 45° along the face



(c) Venturi tilted at 20° down and 30° along the face



(d) Venturi tilted at 20° down and 45° along the face

Figure 6 - Impact of venturi units at different locations on dust particles

The novelty of this new system is its capability to draw sufficient air into the chamber to carry the atomised droplets downstream with sufficient momentum for maximum dust particle attraction and controlled diversion away from the walkway area. In order to utilise the existing water and compressed air supply on the longwall face, the system is built as a stand-alone module with a magnetic base which can be easily attached to the chocks' canopy and adjusted with the right spray angle to achieve the droplet size and velocity needed for dust suppression and diversion, as indicated by CFD modelling. Figure 8 shows the complete prototype water mist venturi systems that are ready for field trials.

Laboratory tests showed that having a ratio of 2:1 air to water seems to produce the best atomisation for the UMV nozzle., i.e. if liquid pressure is 3 bar, ideal air pressure will be 6 bar. Water consumption at 3 bar liquid pressure and 6 bar air pressure is 2.15 L/min or 0.0358 L/s. Air consumption is 35.2 Ncm/hour. The mist produced is of such a fine size that it remains airborne as a "dry fog". As the mist evaporates, it has an evaporative cooling effect which, over a period of time, can have the effect of reducing temperatures on the longwall face.



(a) Ultrasonic nozzle holder assembly with nozzle



(b) Ultrasonic nozzle holder assembly with venturi chamber



(c) The complete venturi assembly



(d) Attaching the venture on the metal wall (canopy)



(e) Laboratory testing of the venturi system



(f) Laboratory testing of the venturi system

Figure 7 - Development of the prototype water mist venture system



Figure 8 - The completed prototype water mist venturi units

FIELD TRIALS

On completion of the design of the water mist venturi systems, it was planned to carry out field trials at longwall faces in the Bowen Basin, Queensland and the Hunter Valley, New South Wales. It was anticipated that the initial trials would involve at least two longwalls, likely Moranbah North, Broadmeadow Mine or South Blakefield. Based upon the initial trial results, the system will be modified, if necessary, and then demonstrated at other mines.

The venturi units will be trialled on the 1-6 MG chocks to knock down and divert the highly concentrated dust clouds from MG chock movements and the BSL. For medium height seam with relatively tight clearance below the chock canopy, the venturi units can be mounted on the top of the longwall Control and Communication Panel and on the AFC-BSL plate, as shown in Figure 9, therefore reducing dust contaminations from 1-3 MG chocks and the belt road. The device will also be trialled near the TG chocks to assist in dispersing methane that builds up around the longwall return corner and to reduce the total dust make from the longwall.

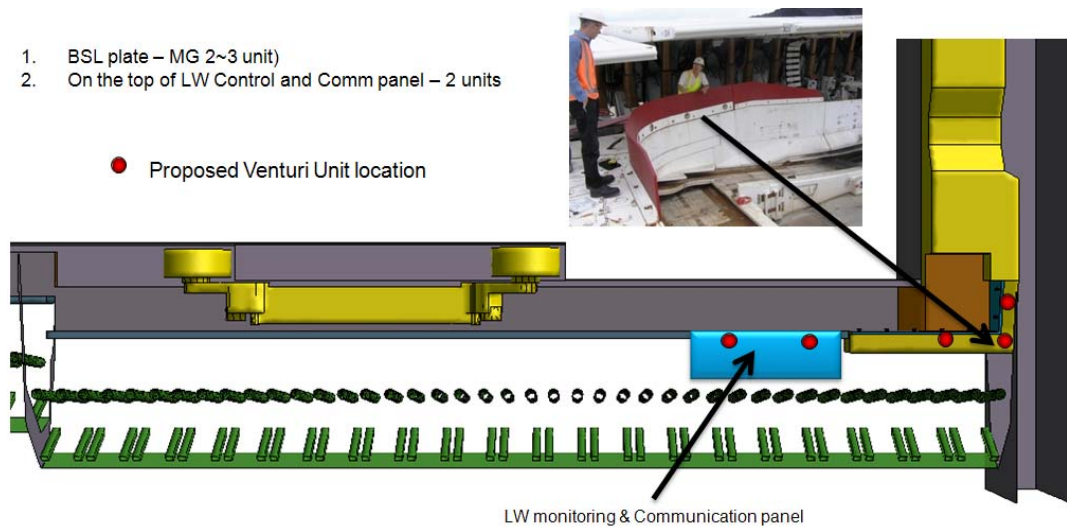


Figure 9 - Proposed locations for installing the venturi units on medium seam longwalls

In December 2010, the first field trials were conducted at Moranbah North and Broadmeadow Mine however the results have not yet been made available for reporting at this stage. Figure 10 shows the venturi units attached to the canopy of a longwall chock before being dispatched to underground longwall face.



Figure 10 - Venturi units attached to the canopy of the longwall chock for field trials

CONCLUSIONS

Chock movement close to the MG has been identified as a significant source of dust exposure for longwall operators when chocks are advanced upwind of the shearer during MG to TG cutting. Extensive CFD modelling studies showed that much of the dust particles will follow the ventilation into the longwall, contributing significantly to longwall workers' dust exposure, if not controlled by effective dust mitigation methods. A new water mist based venturi system has been developed capable of producing ultra-fine water droplets for suppressing dust particles from the MG chocks/BSL whilst inducing a controlled volume of water-mist airflow for diverting the dust clouds off the walkway area. Further field trials of the new venturi system have been planned and will be conducted in Australian longwalls. Applications of this system will greatly reduce dust contamination from longwall chock movements near the maingate, in particular for medium to thick seam longwalls on which dust control appears to be more problematic.

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